Painesville Municipal Electric Power Vanadium Redox Battery Demonstration Project

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Ashlawn Energy LLC

US Produced Vanadium Redox Flow Battery for Bulk Storage, Peak Shaving

- 8 MW Hour redox flow battery (1MW 8 hours)
- To be installed at Painesville Municipal Electric Plant (PMEP), a 32 MW coal fired facility
- Most efficient PMEP operation is steady state at 26 MW (lowest emissions, lowest operating cost)
- Nominal PMEP power demand ranges from 19 MW to 37 MW
- 8 MW Hour battery to demonstrate benefits of energy storage at PMEP

History of Painesville Power

1885 - Established by the Globe Electric Company, the Painesville Council contracted for street lights at $6 per light per month.

1888 - Council sold bonds raising $12,500 to erect an Electric Light Plant on N. St. Clair near Main Street in back of the old Fire and Police Station (now public parking lot). The plant continued in operation until 1908. Municipal Electric Systems in Painesville and was adopted by Resolution 223.

1907 - Painesville Cider and Manufacturing Company property (site of present Light Plant) was purchased for $2,250.

1908 - A new plant was put into operation. The Commercial Electric Company phased itself out of operation around this time.

1923 and again in 1928, large general expansions of the plant facilities created by an increasing demand for electric power in the growing Painesville area.

1923 - a 1500 kilowatt steam turbine generator manufactured by Allis-Chalmers was installed to replace the existing reciprocating engine type generators and continued in operation until the late 1950s. This was the first large steam turbine at the Light Plant.

Additional Coal fired boilers steam turbines generators and allied equipment have been added to the Light Plant over the course of the years.

The American Public Power Association's grouping of Centennial Cities and Towns lists Painesville's system as the 10th oldest in the country of those communities that still operate their systems. In addition, it is one of 14 municipally-owned electric systems in Ohio still generating, and the oldest still in continuous operation.

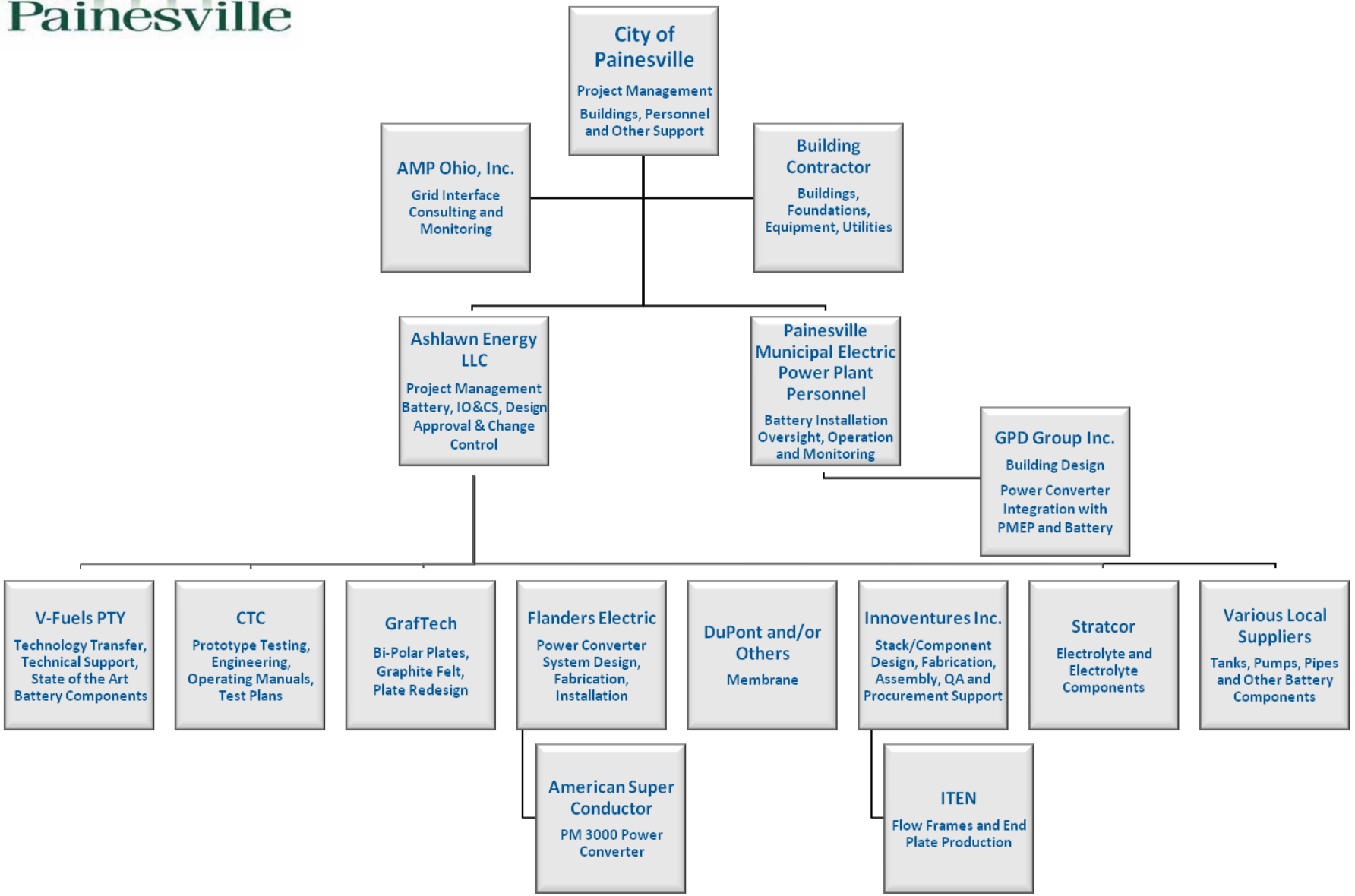
Project has Multiple Objectives

- **Establish/Use US Manufacturing Base**
  - Stack components/stack fabrication
  - Electrolyte
  - Power Conditioning System
- **Demonstrate Efficacy/Reliability of latest Vanadium Redox Flow Battery Design**
- **Cost Reduction**
- **Platform for Commercially Viable Product**

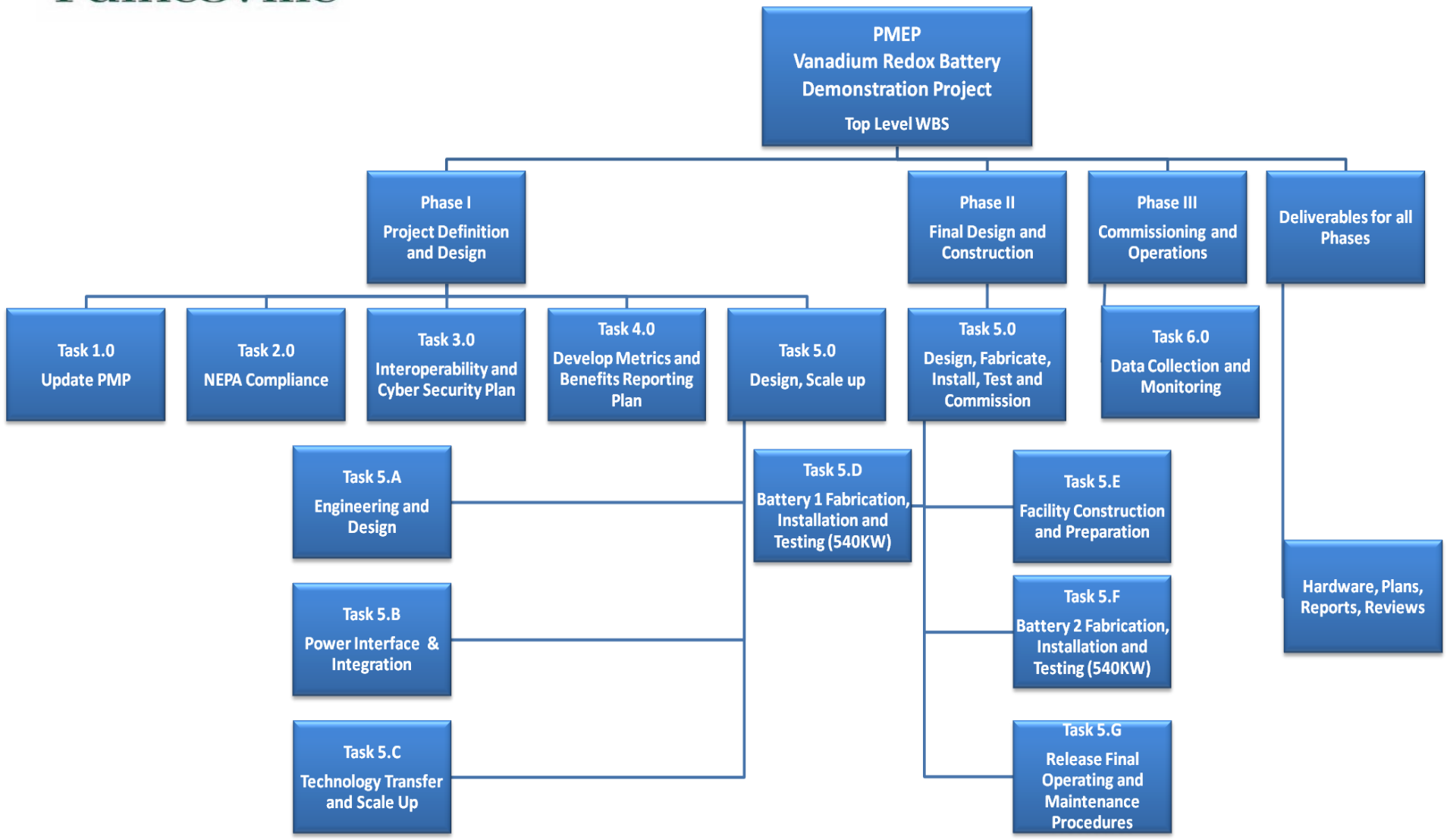
Primary US Based Producers

- GrafTech International – Plates/Felt
- Strategic Minerals Corporation – Electrolyte
- DuPont and/or Other Producers – Membrane
- Innoventures – Stack Components/Stack
- American SuperConductor - Inverter

Project Team

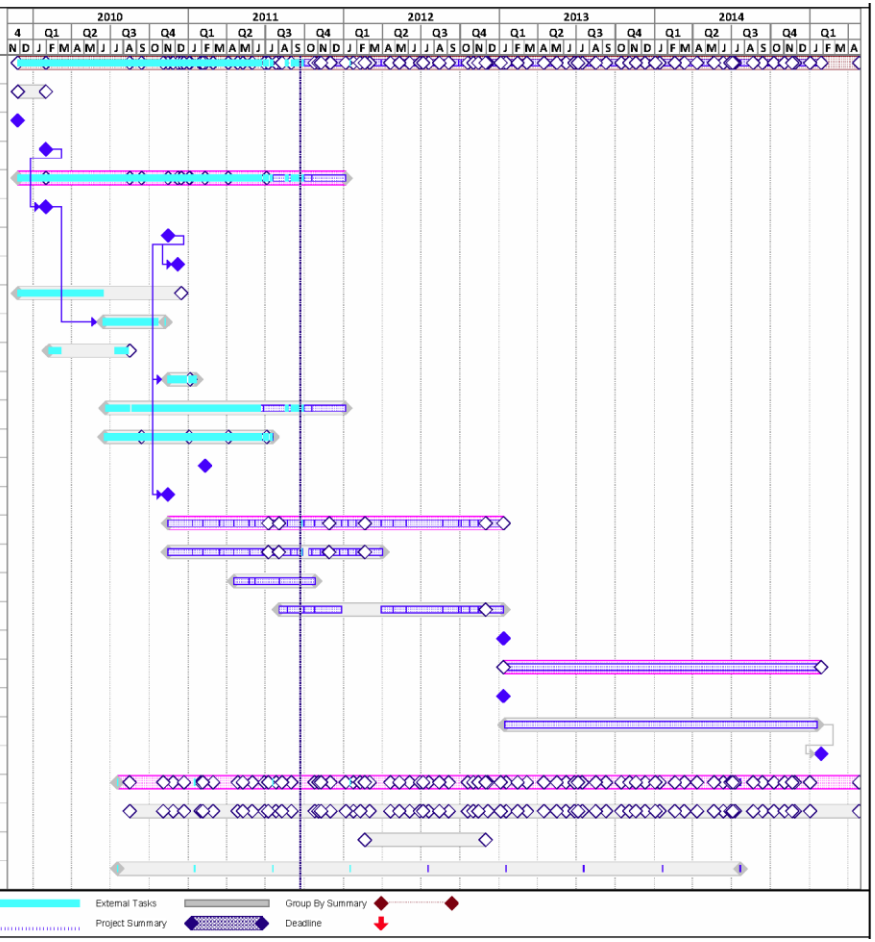


Original Top Level WBS



Original Overall Schedule

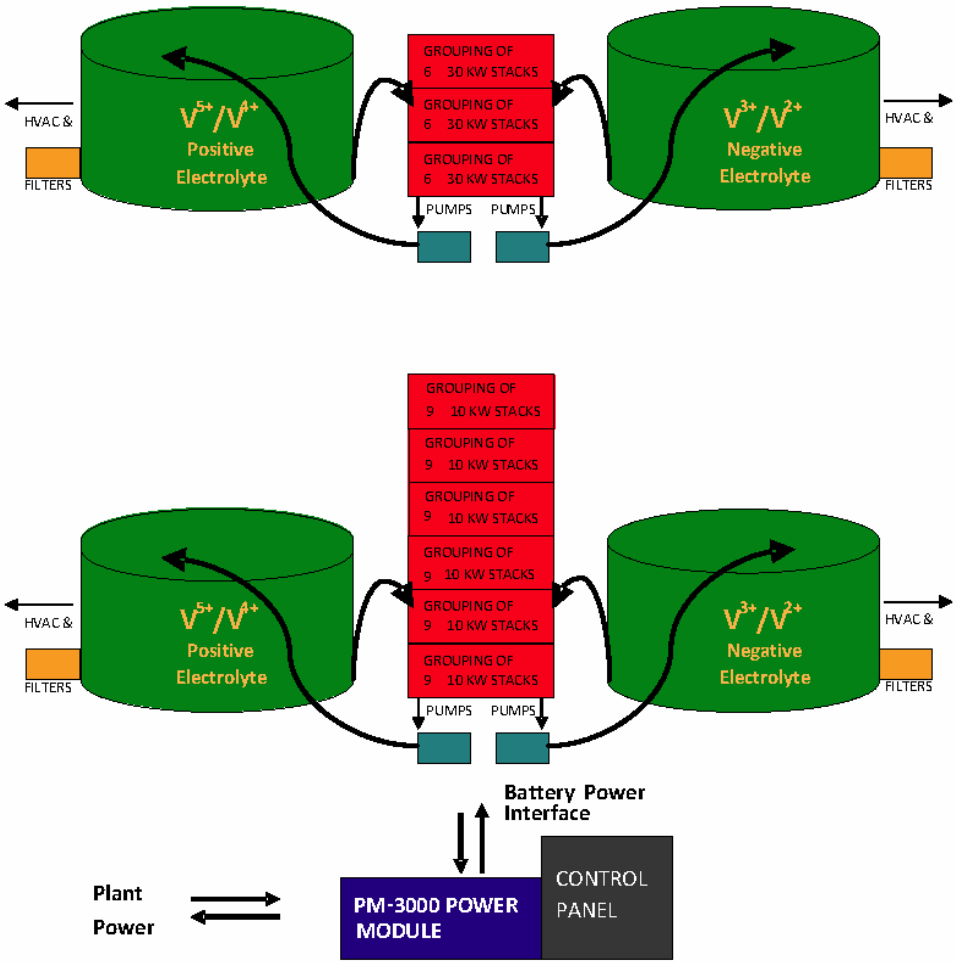
ID	Phase/Task	WBS	Task Name
1	Painesville	1	Painesville Vanadium Redox Battery Energy Storage project
2		1.1	Pre-Award Activities
3		1.1.1	Contract Announcement
4		1.1.2	Contract Agreement Award with Stipulations
5		1.2	Phase I Project Definition and Design
6		1.2.1	Phase I Release
7		1.2.2	Project Definitization Complete
8		1.2.3	Kick Off Meeting
9	Task 1	1.2.4	Update Project Management Plan
17	Task 2	1.2.5	National Environmental Protection Act (NEPA) Compliance
23	Task 3	1.2.6	Develop Interoperability and Cyber Security Plan
28	Task 4	1.2.7	Develop Metrics and Benefits Reporting Plan
33	Task 5.A	1.2.8	Engineering for this Specific Application at PMPP
106	Task 5.C	1.2.9	Technology Transfer and Scale Up
149		1.2.10	10 kW Stack Go/No Go Decision
150		1.2.11	Phase II Release
151		1.3	Phase II Final Design and Construction
152	Task 5.D	1.3.1	Battery 1 Fabrication, Installation and Testing (540kW)
230	Task 5.E	1.3.2	Facility Construction and Preparation
238	Task 5.F	1.3.3	Battery 2 Fabrication, Installation and Testing (540KW and 1.08MW)
271	Task 5.G	1.3.4	Release Final Operating and Maintenance Procedures
272		1.4	Phase III Commissioning and Operations
273		1.4.1	Go/NO GO Decision for Data Collection and Monitoring
274	Task 6	1.4.2	Data Collection and Monitoring
277		1.4.3	Release Final Data Collection Information to Publishing
278		1.5	Deliverables
279		1.5.1	DOE Required Reports
416		1.5.2	Phase II Deliverable Hardware
419		1.5.3	Conference Papers Proceedings and Reviews



Original Improvement Targets

- Vanadium Electrolyte from 1.75 M to 3.12 M
- Stack Size from standard 5 kW to 30 kW
- Power Inverter Efficiency (2% increase)
- Process System Efficiency (5% increase)
- Reduced foot print

Original Battery Layout



Modular Design

Painesville building block – 5 kw stack
1 Module below of 100 kw is made up of 20, 5 kw stacks

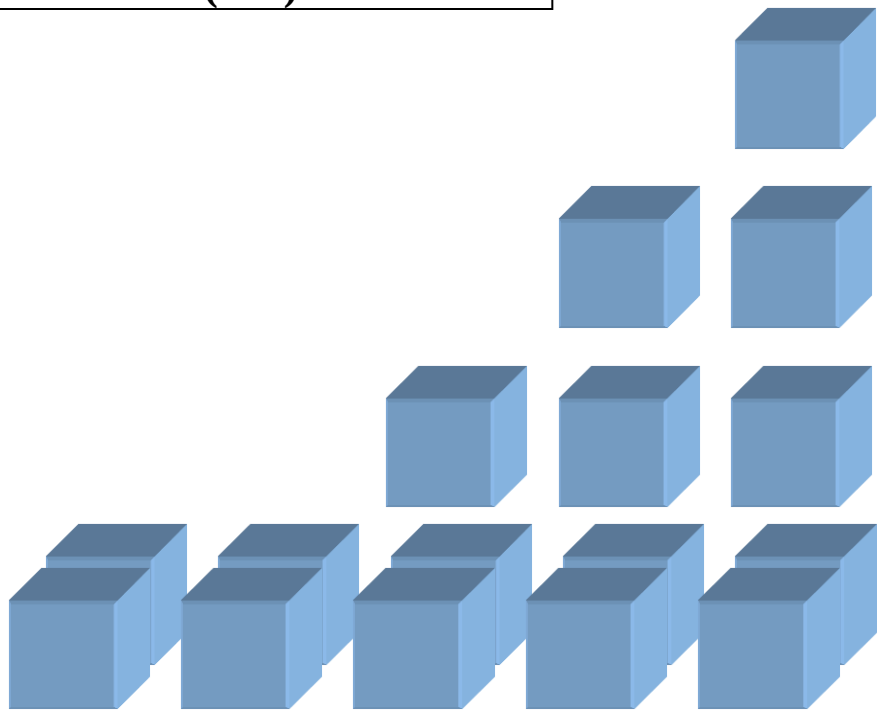
Continuous Discharge Rate (kW)

1 Module (100 kW)

2 Modules (200 kW)

3 Modules (300 kW)

10 Modules (1MW)



Modular Design

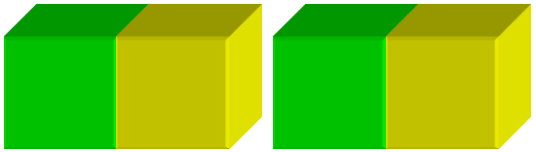
Vanadium Electrolyte Modules

Painesville Storage time
The amount of Vanadium Electrolyte dictates storage time in hours

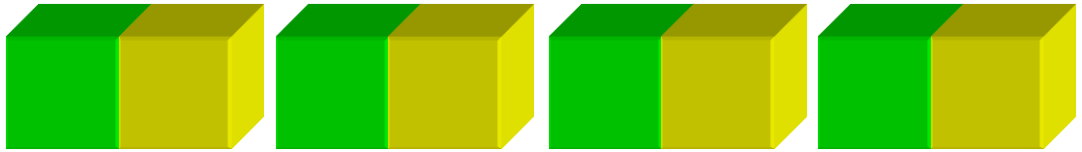
Capacity (kWh)

250 kWh = 3,000 G

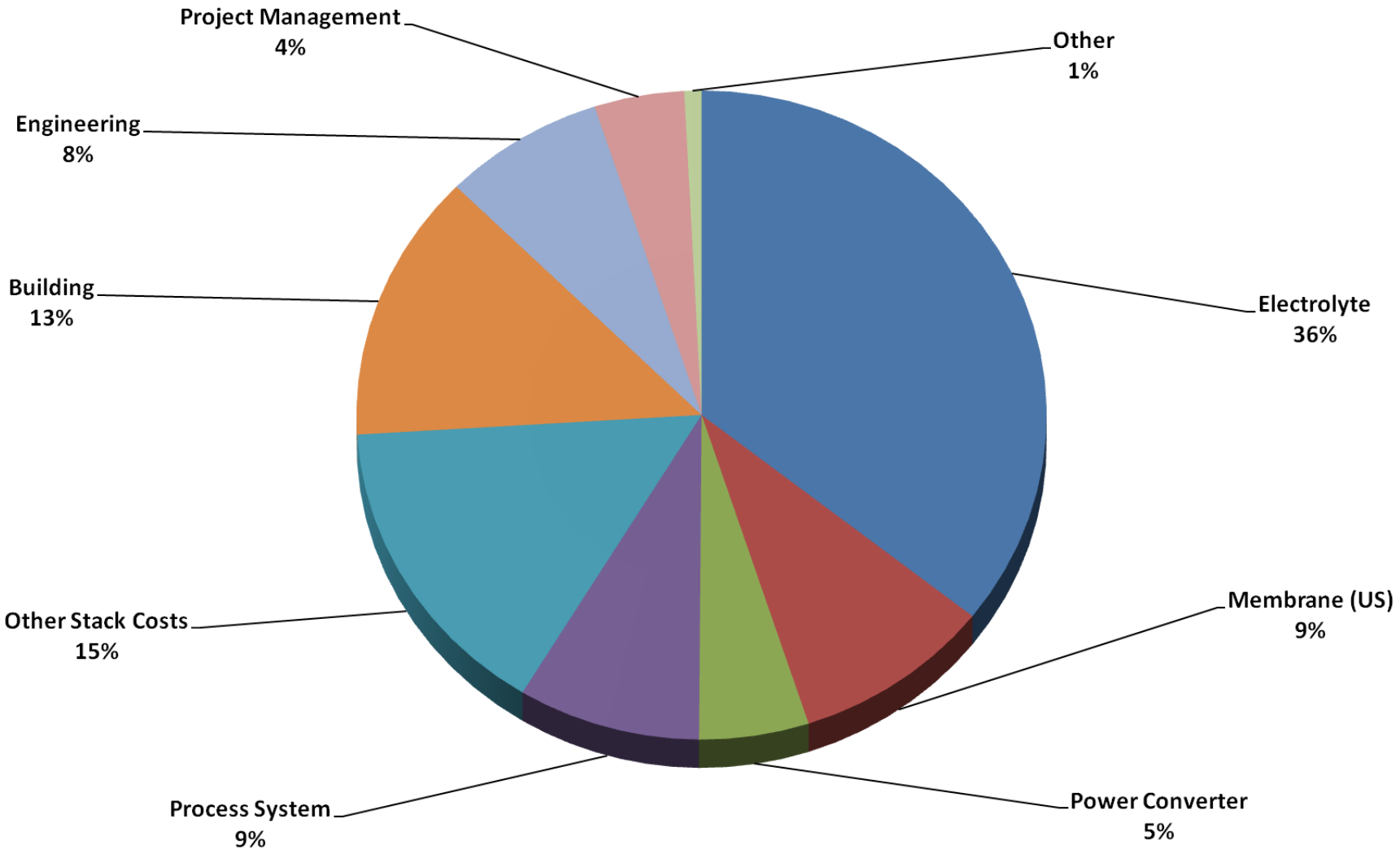
500 kWh = 6,000 G



1 MWH = 12,000 G



Major Cost Drivers at Start



Project Risk Analysis

- 10 kW stack prove out and electrolyte pricing are key to meeting cost targets
- Process design schedule confirmation is key to meeting building schedule
- Higher molar electrolyte is key to storage time target
- Process design changes will demonstrate round trip efficiency improvements

Progress To Date

- **Status in Selected Areas**
  - 250 watt, 2.5 kW and 10 kW prototypes Fabricated
  - Battery Test Bed System Operational
  - Electrolyte Prototype Production/Conversion Line Complete
  - Target Building Footprint Achieved/Building Site/Design Complete
  - Building Contract Awarded
  - Flow Frame Mold Steel Released for Purchase
  - Various Membranes, Bi-Polar Plates and Felt Tested
  - Improved Flow Frame Design/Fabrication Complete
  - 7 Potential Patents Identified/2 in Process
- **10 kW Stack Milestone Test to Complete End October**
- **Lower Cost Components in Queue for Testing**

Cyber Security & Interoperability

- **Cyber Security/Interoperability Plan Submitted and Accepted by DOE**
  - CISO (Chief Information Security Officer) employed and active
  - Member: NIST Smart Grid Interoperability and Cyber Security Working Group (SGIP/CSWG)
  - Program represented at DOE Cyber Security Information Exchange in Chicago, Summer 2011
- **Cyber Security Plan in effect**
  - Incident Response Team assembled: contact information posted
  - Administrative team assembled: coordinates with CISO
  - Cyber Security best-practices distributed to team and potential vendors

Cyber Security & Interoperability

(Continued)

- **Threat Reduction / Risk Analysis**
  - Project will be air-gapped from plant SCADA (No Remote Data Communications)
  - Not enough current to cause ripple electrical disturbance at PMEP
  - Battery Control System will be locked and secured per applicable NERC standards
  - DOE-approved security policies will be in effect for all information systems

CITY OF Painesville

Painesville Municipal Electric Power Plant

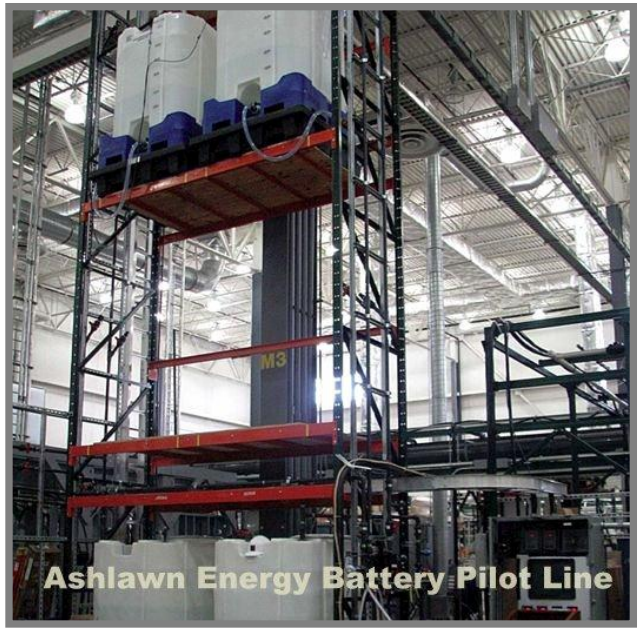
Battery Building Site

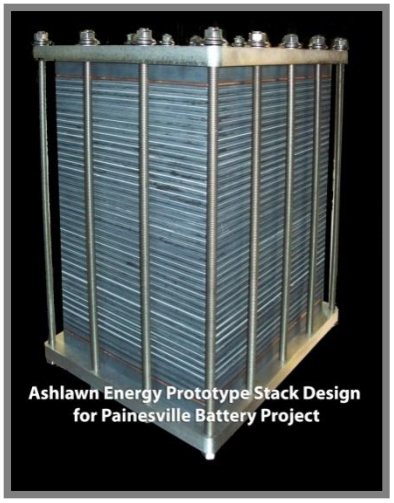
ASHLAWN ENERGY

CITY OF Painesville

ASHLAWN ENERGY

Various Stacks & Prototype Lines



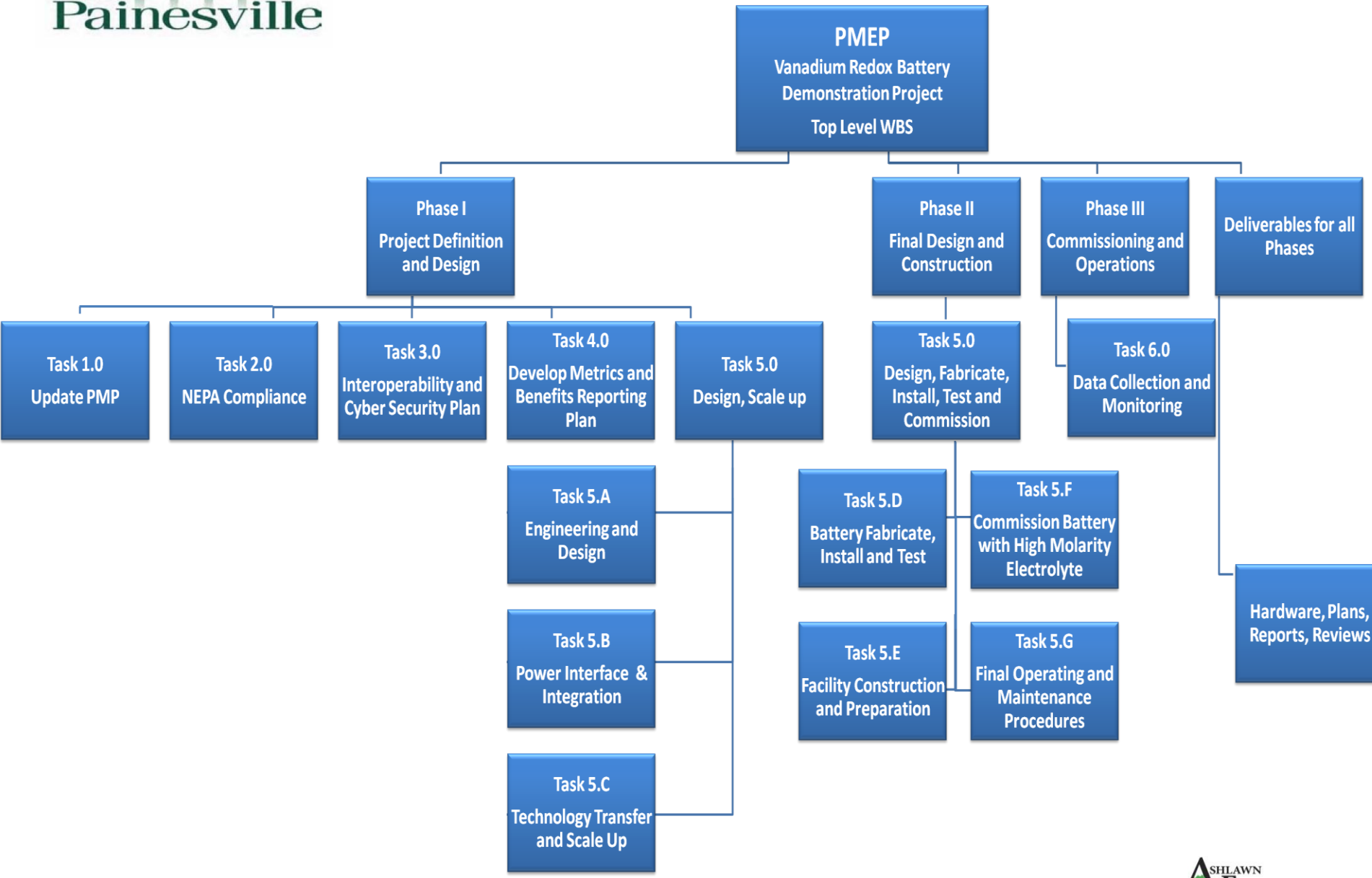


Project Approach Changed Based on the Outcome of Tests on Various Design Improvements

Current Improvement Targets

- Operational Stack Size from 10 kW to 20 kW
- 30 kW Prototype Prove Out
- Power Inverter Efficiency (2% increase)
- Process System Efficiency (5% increase)
- Mixed Acid Vanadium Electrolyte

Current Top Level WBS



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92	Task 5.B	2.9	Power system interface and integration
93	Task 5.C	2.10	Technology Transfer and Scale Up-CTC Test Matrix
165		2.11	Phase II Release
166		2.12	Freeze Flow Frame Design for 10 kW Stack Frame
167		2.13	10 kW Stack Go/No Go Decision
168		2.14	Mixed Acid Go/No Go
169		3	Phase II Final Design and Construction
170		3.1	20 kW Split Stack Go/No Go Decision
171	Task 5.D	3.2	Battery Fabrication, Installation and Testing (1.08 MW)
255		3.3	Release 8 MW hour Battery For Operations
256	Task 5.E	3.4	Facility Construction and Preparation
265	Task 5.G	3.5	Release Final Operating and Maintenance Procedures
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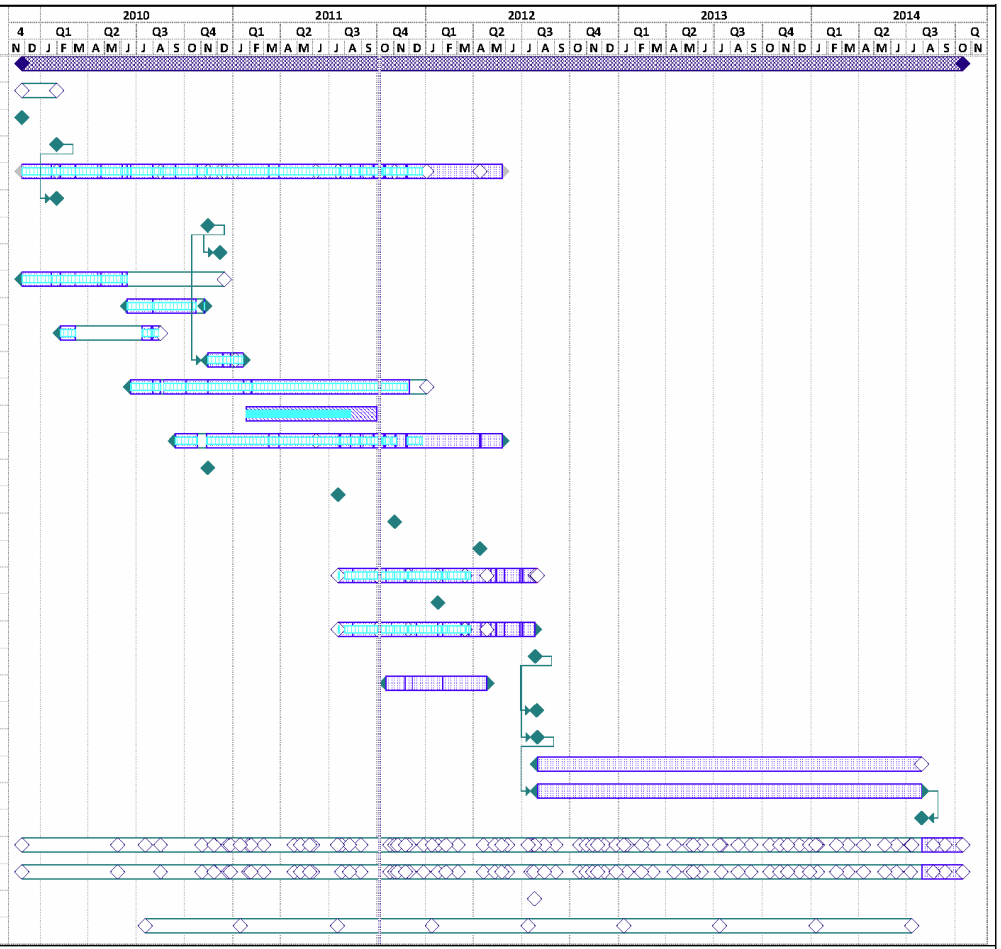
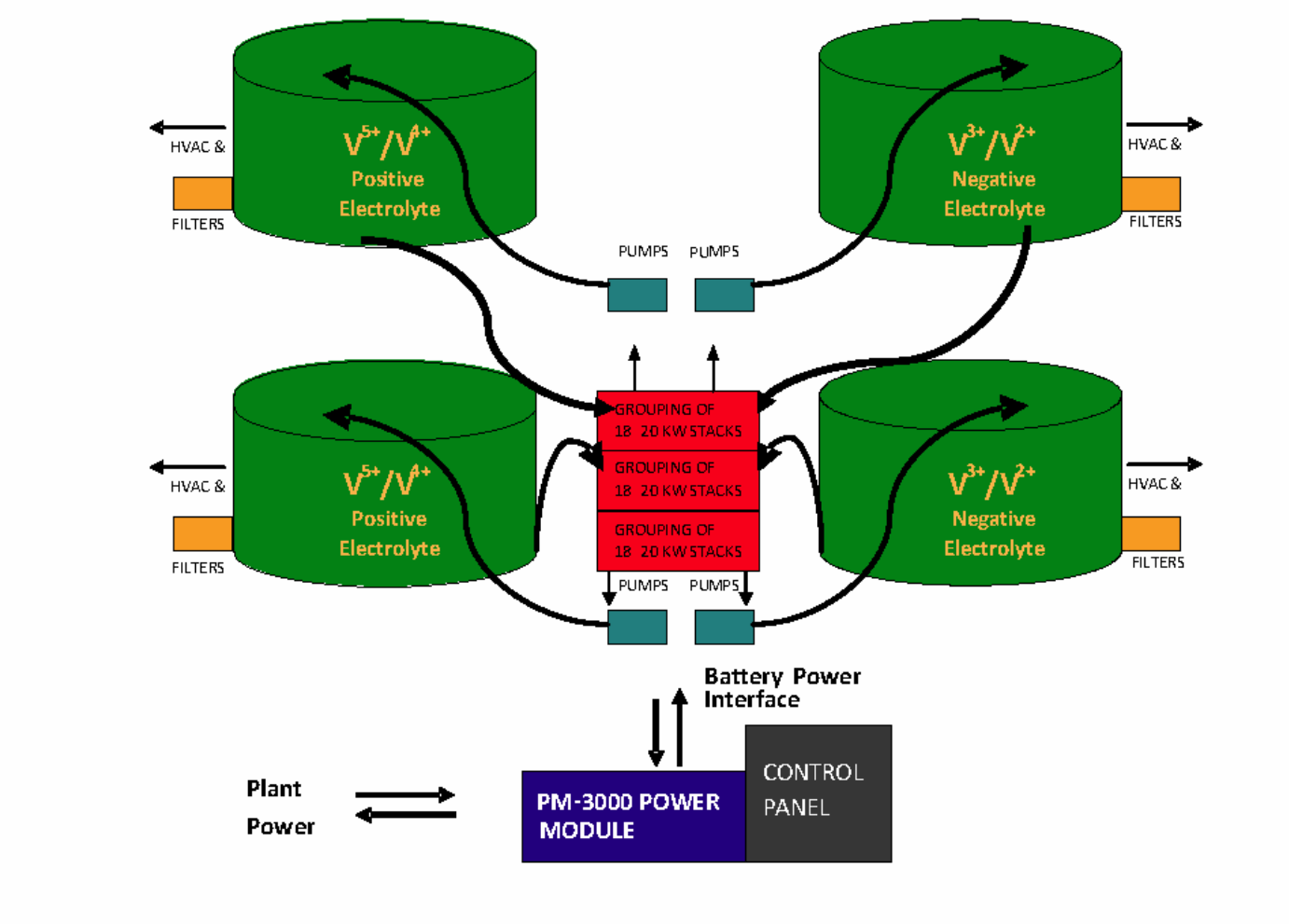


Current Battery Layout



Modular Design

Stack Modules-Higher Power

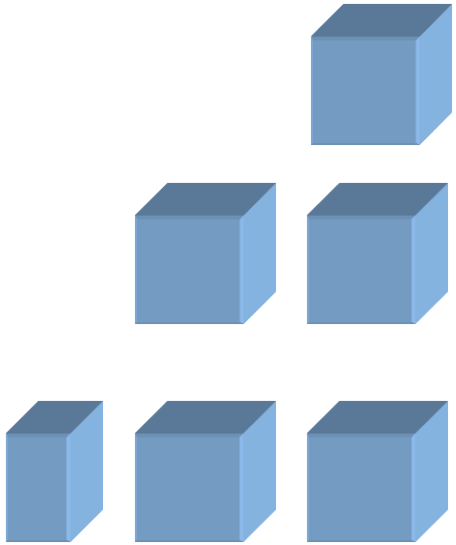
Painesville building block – 20kw stack
1 Module below of 400 kw is made up of 20, 20kw stacks

Continuous Discharge Rate (kW)

1 Module (400 kW)

2 Modules (800 kW)

2.5 Modules (1 MW)



Modular Design

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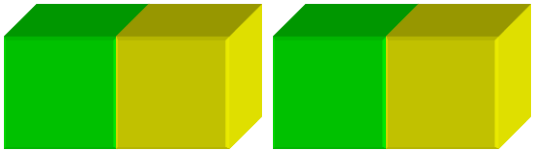
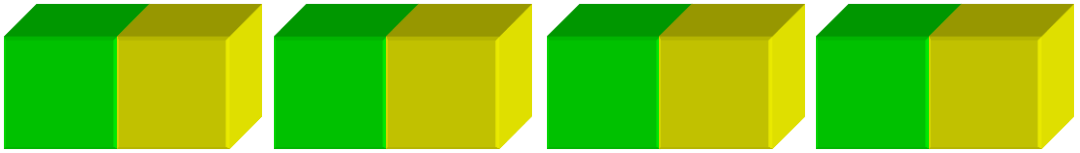
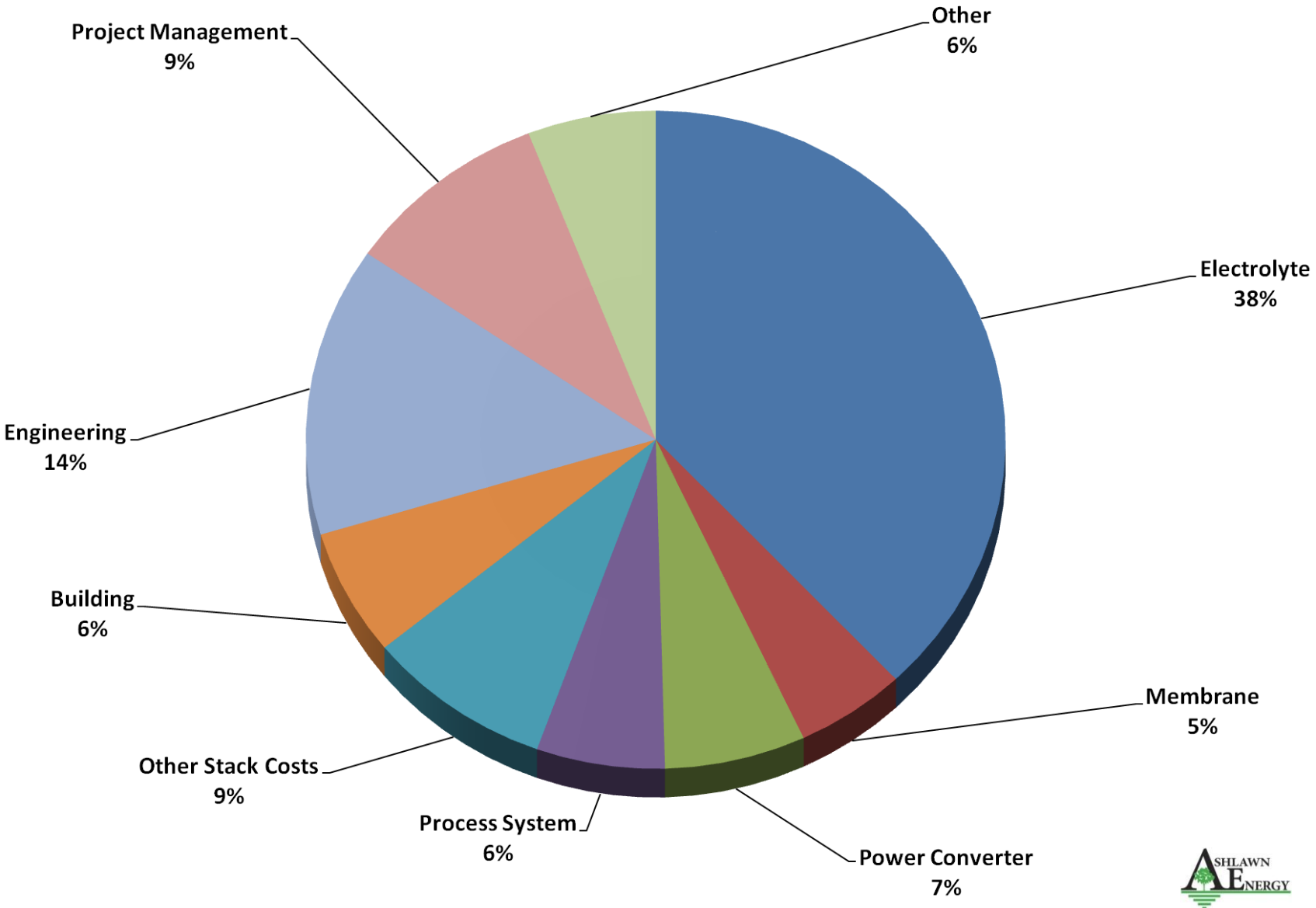
500 kWh = 4,200 G



1 MWH = 8,800 G



Major Cost Drivers at Present



Distribution of Cost Factors

- Molded Flow Frames
- Lower Membrane Costs
- Graphite-Coated Collector Plates
- Bonded Felt
- Composite End Plates
- 10 kW Stack Prove Out
- 20 kW Stack Design

Summary/Conclusions

- Project will complete well ahead of original schedule and is currently over budget
- Test bed confirmation of higher molarity electrolyte is key to storage time target
- Design Improvements have reduced costs
- Test bed confirmation of process design changes will demonstrate round trip efficiency improvements

Future Tasks

- Complete Operational Testing of Prototypes
- Building Construction
- Long Lead Orders on Manufacturing Equipment/Components
- Balance of Plant Final Design
- Inverter Design Modifications
- Competitive Bids on Components (all US)

Painesville Municipal Electric Power Vanadium Redox Battery Demonstration Project

Questions?